A Luneburg Lens for Spin Waves

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EPSRC Centre for Doctoral Training in Metamaterials XM²

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Abstract. We report on the theory of a Luneburg lens for forward-volume magnetostatic spin waves (FVMSWs), and verify its operation via micromagnetic modelling. The graded index profile is realized here by either modulating the thickness or the saturation magnetization in a circular region. We find that the lens enhances the wave amplitude by 5 times at the lens focus. Furthermore, we find that small deviations in the profile can still result in good focusing, if the lens index is still graded smoothly.

Introduction

The Luneburg lens [1] is a well-known graded refractive index profile (Fig. 1(a)), designed to **focus a plane wave to a point**, and **convert a point source to a plane wave** (Fig. 1(b)).

This profile has been studied in many other areas of wave physics [2-4]. Being **rotationally symmetric**, it could be used to read/launch plane waves from/to any direction, **without reconfiguring the lens**.

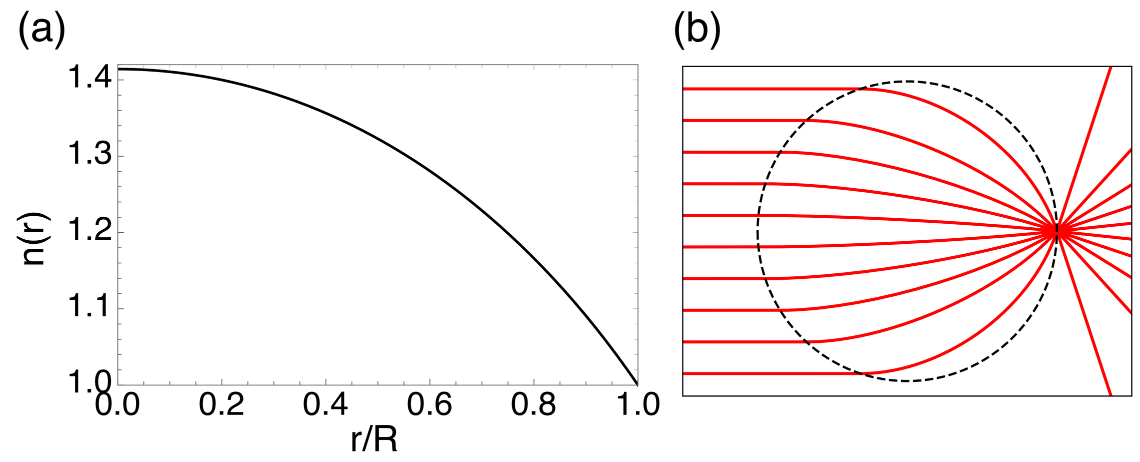


Fig. 1: Properties of the Luneburg lens, with radius R. (a) Refractive index profile n(r), with r the radial coordinate. (b) The lens (black outline) focuses rays (red lines) to a spot on the opposite edge of the lens.

We demonstrate how to create a Luneburg lens for FVMSWs analytically and using Mumax3 software [5], and analyse its ability to focus a plane wave to a point, and vice versa.

Background Theory

The refractive index profile n as a function of radial coordinate r for a Luneburg lens of radius R is given by

$$n(r) = \frac{k(r)}{k_{\mathrm{ref}}} = \sqrt{2-(r/R)^2},$$

where the spin waves inside and outside of the lens have wave-numbers $k(r)$ and k_{ref} respectively. To work in the intended limit of geometrical optics (Fig. 1 (b)), $R >> \lambda$ (the wavelength).

We can determine k from the dispersion relation, given by

$$k = \frac{1}{s}\left[\arctan\left(\frac{1}{\sqrt{-(1+\kappa)}}\right)\right]\frac{2}{\sqrt{-(1+\kappa)}},$$

for FVMSWs in a thin film, where s is the film thickness, and

$$\kappa = \frac{\Omega_H}{\Omega_H^2-\Omega^2}, \quad \Omega = \frac{\omega}{4\pi\gamma M_S}, \quad \Omega_H = \frac{H_i}{4\pi M_S},$$

with M_S the saturation magnetization, $H_i = H_0 - 4\pi M_S$ the internal magnetic field, and H_0 the applied external field. To change k in space, **we can vary $s(r)$ most easily** (Fig. 2(a)) - although **$M(r)$ is easier to change in micromagnetic modelling** (Fig. 2(b)).

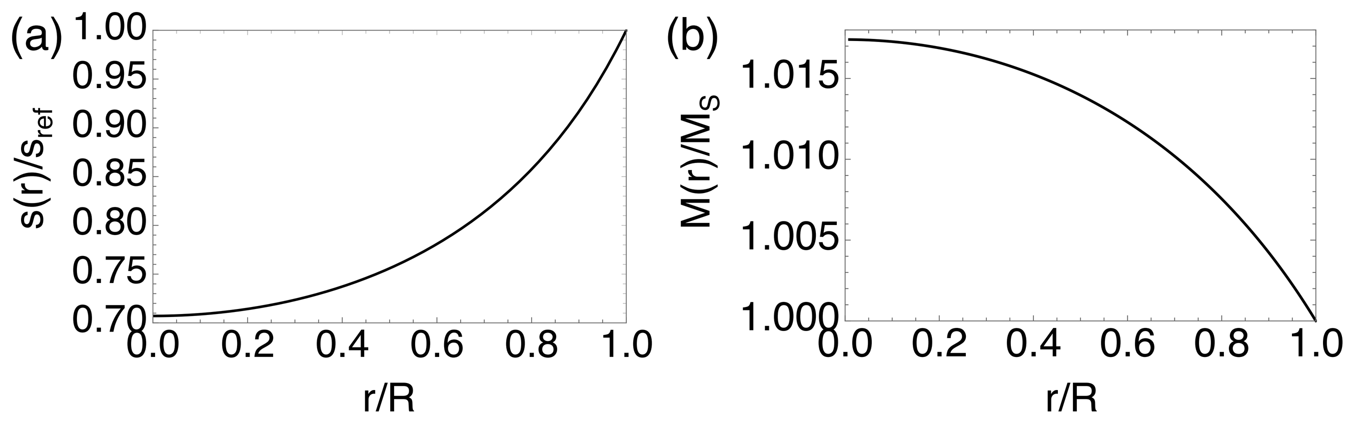


Fig. 2: The (a) thickness profile and (b) magnetization profile required to make a Luneburg lens.

Results & Discussion

We vary M in space, with M(R) = 140kA/m for a YIG-like film.

The lens **focuses an incident plane wave** pulse (Fig. 3) - amplitude at the focus amplitude is **5 times** incident amplitude (Fig. 4). A **plane wave** can be launched from any point on the edge of the lens via a Gaussian point source (Fig. 5).

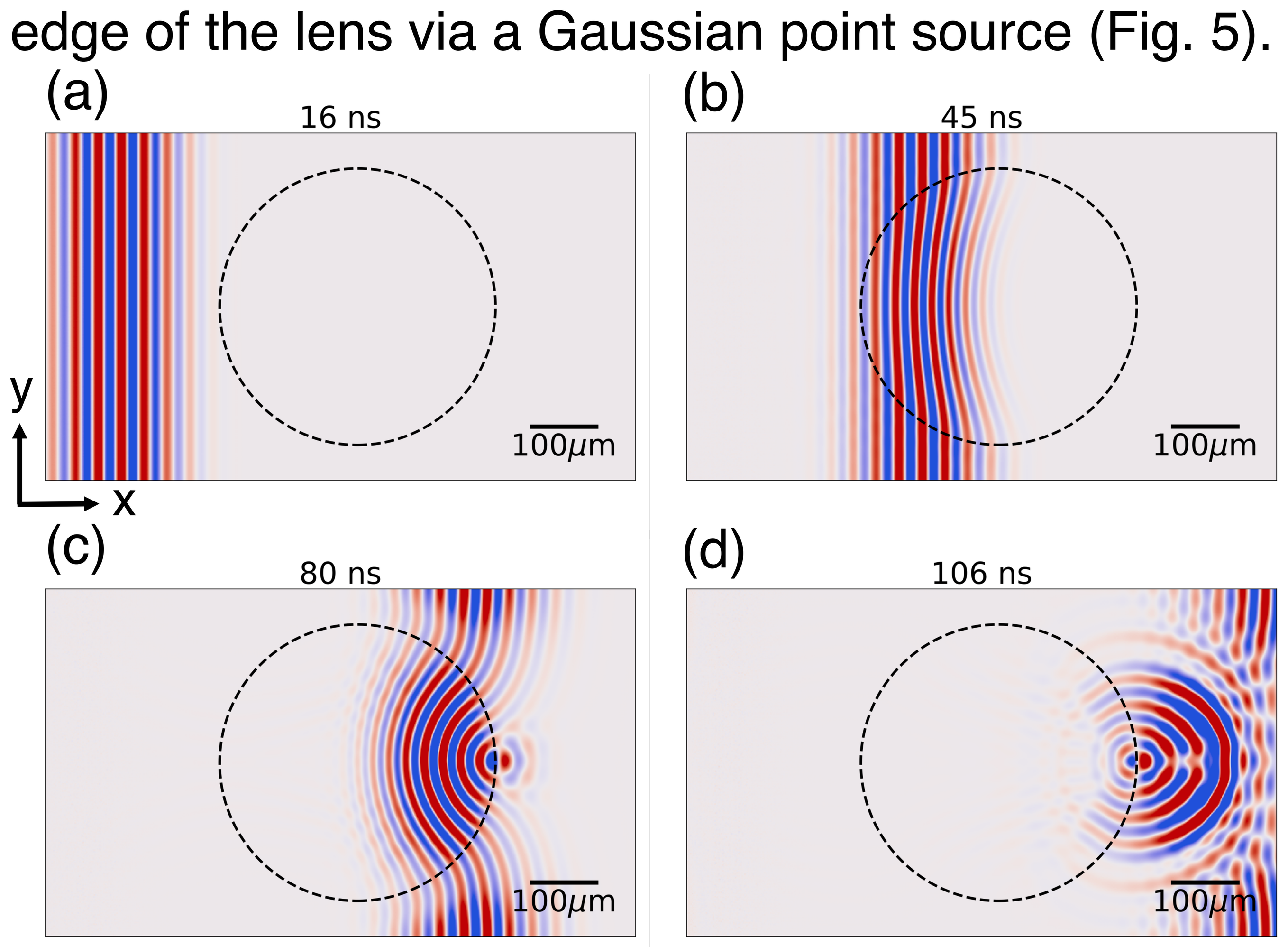


Fig. 3: (a)-(d) Snapshots of pulse moving through Luneburg lens (dotted outline) with corresponding video in (e).

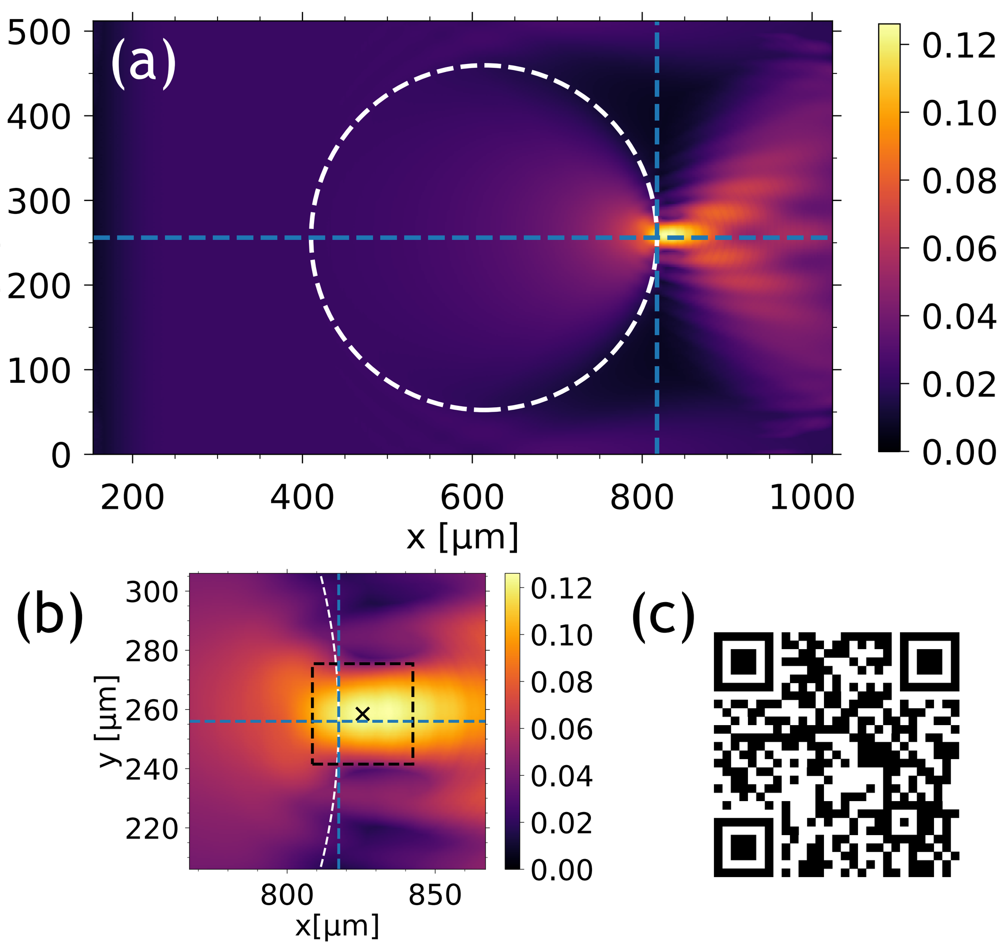
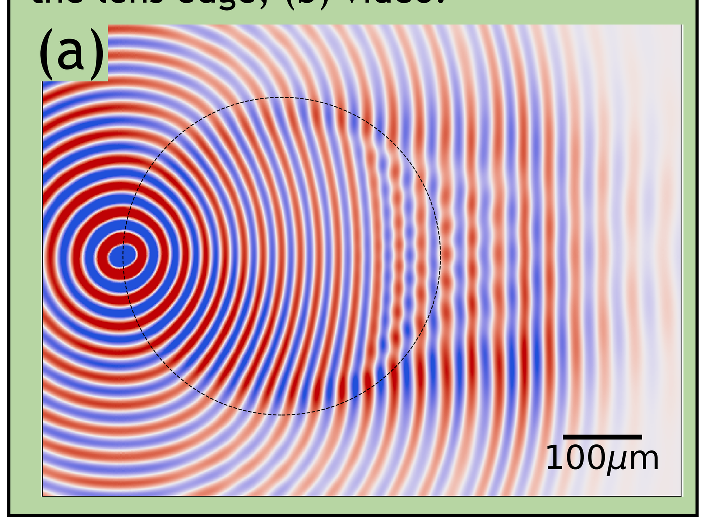


Fig. 4: (a) Maximum amplitude of m_x attained across the model over entire duration of the simulation (corresponding video shown in (c)), with zoom of focus shown in (b). Scale maximum is peak amplitude.

Parameters: ***Model****: x-y dimensions≈1mm x 0.5mm, x-y cell size = 0.5μm, s=2μm (1 cell across z). M_S=140kA/m=M(R), H_0=200mT, damping α= 1x10^{-4}.* ***Pulse****: frequency f= 1GHz (λ≈ 34μm), bandwidth =0.1f, normalized m_x amplitude = 0.025.* ***Lens****: R≈6λ.* ***Images****: Normalized m_x component shown, image snapshots saturated for clarity.*

Fig. 5: (a) Plane wave created from continuous Gaussian source, located at the lens edge, (b) video.



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This research has received funding from the European Union's Horizon 2020 research and innovation program under Marie Skłodowska-Curie Grant Agreement No. 644348 (MagIC).

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